THE 16 CYLINDER AIR-COOLED DIESEL ENGINE OF THE SIMMERING GRAZ PAUKER A.G.

Report prepared by

FIELD INFORMATION AGENCY, TECHNICAL
UNITED STATES GROUP CONTROL COUNCIL FOR GERMANY

BRITISH INTELLIGENCE OBJECTIVES
SUB-COMMITTEE

LONDON—H.M. STATIONERY OFFICE

OFFICE OF MILITARY GOVERNMENT FOR GERMANY (US)
FIELD INFORMATION AGENCY, TECHNICAL

FIAT FINAL REPORT NO. 593

17 December 1945

THE 16 CYLINDER AIR-COOLED DIESEL ENGINE OF THE SIMMERING GRAZ PAUKER A.G.

BY

A. M. MADLE

JOINT INTELLIGENCE OBJECTIVES AGENCY

FIELD INFORMATION AGENCY, TECHNICAL.

TABLE OF CONTENTS

I. INTRODUCTION

Approximately in 1941 a general request was issued to German industry to concentrate on the development of air-cooled engines for all military applications. Simultaneously the trend towards employing the Diesel type engine became very strong.

To illustrate the scope of development work on engines for heavy armoured vehicles a table is attached (Fig. 1).

The optional power indication of this table for the Simmering Graz Pauker, type SLa 16 of 800 HP refers to a projected increase in the bore size from 135 mm to 140 mm.

The Simmering Graz Pauker A.G., manufacturer of Diesel engines for stationary and railroad applications, was ordered to build engines of Dr. Porsche's design. This engine was originally planned to be a Diesel, but, due to entirely unsatisfactory performance finally emerged as a 10 cylinder V, air-cooled Carburettor engine.

The engine, however, still was unsatisfactory and in 1942 the Simmering Graz Pauker A.G. scrapped parts for 500 engines.

It was then that the company either resolved, or was requested, to develop an air-cooled Diesel engine of their own, and this became the engine under discussion.

The engine was planned to replace the Maybach type HL 230 tank engine and therefore had to be designed to fit the space allotted to the latter, which demand imposed quite serious restriction on the construction. Five of these engines were finished in 1944. After intensive blocktesting, one of them was installed into a new 180 ton tank at the company's "Nibelungen" plant at St. Valentin in January 1945.

Since these tests were satisfactory beyond expectation, the Simmering Diesel outperforming the Maybach engine in every respect, it was decided, in March 1945, to put the engine into production. Due to the simultaneous collapse of the German industry, however, nothing more was done towards filling the order.

The first information about the existence of such an engine was obtained from Norbert Riedel, Muggendorf, near Nuernberg, who stated that he was designing a starter engine for it.

II. CONCLUSION

The 16 cylinder, air-cooled, supercharged Diesel engine type SLa 16 of the Simmering Graz Pauker A.G. deserves interest, not only because it constitutes the most modern, successful development in its field, but also because of the multitude of novel features employed in its construction, and its clean cut, well matured design.

There do not seem to exist any prior reports on this engine, other than its casual mention amongst the products of the Simmering Graz Pauker A.G., in the evaluation report, which carries the remark that the plant is completely destroyed or evacuated.

III. GENERAL DESCRIPTION OF THE STRUCTURE (See fig. 2, 3, 4, 5, 6, 7, and 8)

The 16 cylinders of the engine are arranged in a "flat X" with 135 degrees included angle, in four banks with four cylinders each. The crankshaft has four cranks and since four cylinders are in the same plane, three of the connecting rods are linked to one master rod. The crank angles and positions of the master rods are important for the balance of the engine and in the produced engine the successive crank angles are 180, 90, and 180 degrees while all master rods are in the same bank of cylinders. It was planned, however, for the production engine, to reverse the direction of alternating master rods. (See fig. 9)

The overhead valves are inclined in the center plane of the respective cylinder bank. They are operated by rocker arms, parallel pushrods guided in the head, and roller tappets with ball joints, from a camshaft for each bank. The four camshafts are driven from the crankshaft by an arrangement of spur gears. (Fig. 8 and 11)

The engine is supercharged by two Exhaust Turbo Blowers of the "Buechi" type, each supercharger being operated by and supplying two banks of cylinders, located on the same side of the engine.

There are two cooling blowers provided, one on each side of the engine, so arranged that the cooling air is drawn from the atmosphere, past the cylinders and cylinder heads. A part of the air through the blower is drawn from atmosphere through the oil coolers (two per blower). (See fig. 10) The blowers are driven from the crankshaft, through a train of bevel gears and shafts. (See fig. 2, 3 and 6)

The injection system is of a modified Bosch design. There were four injection pumps provided at the power take-off side of the engine and driven through a shaft and bevel gear train from the idlers of the timing gear train. (See fig. 15). It was planned to change the injection system to the employment of only two pumps to facilitate governor adjustment.

A pressure lubricating system is provided, employing one suction and one pressure pump, discharging through oil coolers, and filters to the bearings. Cylinder lubrication is supplied by the overflow of the bearings and throwoff from the cranks.

Since the SLa 16 engine with a maximum speed of 2000 R.P.M., had to replace the Maybach HL 230 engine with a maximum speed of 3000 R.P.M., it was necessary to provide a power take-off gear train, effecting a speed increase of 1: $1\frac{1}{2}$. (See fig. 12 and 15).

IV. ENGINE SPECIFICATIONS

Maker: . . . . Simmering - Graz - Pauker A.G.
Vienna, XI., Austria
Simmeringer Hauptstrasse
Service. . . . . Tank engine (original purpose)
Model No.: . . . . Sla 16

Type:. Diesel-Supercharged
Cycle: 4
Number of Cylinders: . . . . 16. In flat X arrangement - 135 degrees included angle

---

Bore: . . . . 135 mm - 5.315"
Stroke:. . . . . 160 mm - 6.300"
Displacement:. . . . . 36800 ccm - 2240 cb. in.
Compression Ratio: . . . . 14.5 (supercharged)
Weight:. . . . . 1850 kg. - 4070 lbs. (without blowers)
2250 kg. - 4960 lbs. (complete)

Performance:

(a) Data in Fig. 16 are from the one-cylinder tests.

(b) Block Test Results:

	At crankshaft excl. blowers	At take-off shaft, incl. blowers
Power	750 HP	620 HP
RPM	2000 RPM	3000 RPM (2000 RPM crankshaft)
B.M.E.P.	130.5 p.s.i.	108 p.s.i.
Piston Velocity	2100 ft./min.	2100 ft./min.
Economy	.440 lbs./HP/h.	.533 lbs./HP/h.
Weight per HP	5.42 lbs./HP	8 lbs./HP
Power sq.in.Piston Area	2.12 HP/sq.in.	1.74 HP/sq.in.
Economy at 3/4 load, 1600 RPM		.374 lbs./HP.h.

Crank Case (See Fig. 13 and 14)

Two part, welded steel structure
Cylinder Spacing 215 mm - 8.46".

Cylinder. (See fig. 17 and 25).

Individual steel forging of Chrome Steel. 220 Brinnel hardness. Ribs machined.

Cylinder Head. (See fig. 25 and 26).

Permanent Mold Hydronalium Casting. (Hydronalium: 4% Magnesium, traces of Copper and Iron, balance Aluminum). Cast by Nueral, Nuernberg. Similar to Cylinder Head of BMW Mod. 801 Aircraft Engine. Head to Cylinder connection by shrink thread.

No Cylinderhead Gasket.

Combustion Chamber. (See fig. 18 and 25).

Pre-chamber system especially developed for supercharged engine. Pre-chamber contained in separate Hydronalium casting, bolted to the cylinder head with three bolts. Upper part of pre-chamber is formed by a cavity of the casting. Venturi passage and burner inserted heat resisting steel (19% Chromium). Slotted burner jet. Combustion chamber formed for inclined valves. Dished piston head.

Piston: (See fig. 18 and 19).

Permanent mold casting of Aluminum. 6 Piston rings, one of which is below wristpin. Compression Rings: 4 Bi-metal (see fig. 19), 6 mm thick, 5 mm radial. Oil Rings: U section, 7 mm thick, 5 mm radial. (All rings purchased from Tewes, Frankfurt.)

Crankshaft. (Seefig. 9 and 32).

Forged of case-hardening Chromium - Manganese Steel. Hardened to 58 Rockwell C. Core hardness 31 - 32 Rockwell C. It was planned to use Nitriting Steel in production. Four cranks. (For crank angles see fig. 9). Five Main Bearings.

Main Bearings.

Material: Copper-Lead. - Steel backed. Bore: 90 mm - 3.54". Length: 60 mm - 2.36" (65 mm - 2.57" incl. radii. Wall thickness: 7 mm - .276". Thickness of Copper-Lead: .75 mm - .0295".

Connecting Rod Bearings. (See fig. 39)

Material: Copper Lead, Steel backed. Bore: 90 mm - 3.54". Length: 85 mm - 3.350". Wall thickness: 7 mm - .276". Thickness of Copper-Lead: .75 mm - .0295".

Piston Pin Bearing. (See fig. 40).

Material: Bronze with slight Tin content. Diameter: 48 mm - 1.890". Length: 60 mm - 2.360". Wall Thickness: 4.5 mm - .177".

Piston Pin.

Floating, axially limited by snap rings (Seeger Rings).

Connecting Rods. (See fig. 20, 34 and 35).

One Master rod and three Link rods per crank. Material: VMS - 175, heat treated to 35 - 38 Rockwell C.

Inlet Valve. (See fig. 27).

Port Diameter 60 mm - 2.360"; 44.4% of bore. Lift: 10.5 mm - .414". Seat Angle: 30 degrees. Material: Flw 1445 (A1). Carbon: .30 - .50; Silicium: .3 - .8; Maganese: 17.0 - 19.0; Chrome: 3.0 - 3.5.

Exhaust Valve. (See fig. 28).

Sodium cooled. Port Diameter: 56 mm - 2.200"; 41.4% of bore. Lift: 10.5 mm - .414". Seat Angle: 45 degrees. Material: Flw 1545 (A4). Carbon: .4 - .6; Silicium: 2.0 - 4.0; Chrome: 8.0 - 12.0.

Valve Springs. (See fig. 25).

Two springs within each other. 193 lbs. at .414" lift.

Valve Seats. (See fig. 25).

Material: Special C.I., pressed and shrunk into head.

Valve Timing.

Intake opens: 62 degrees B.U.D.C.; closes: 35 degrees A.L.D.C.
Exhaust opens: 45 degrees B.L.D.C.; closes: 72 degrees A.U.D.C.
Overlap: 135 degrees.

Valve Mechanism. (See fig. 7, 24).

Overhead valves, controlled by parallel rocker arms, push rods and roller tappets with ball joint from one camshaft per bank of cylinders. The four camshafts being driven from the crankshaft, through a train of two idler gears.

Lubrication.

Pressure lubrication with two pumps in series -71 p.s.i. pressure. From pressure pump through Oilcooler, Filter, to bearings. Cylinder and Piston lubrication by splash.

Oil Consumption.

.009 lbs./HP/hour (approximately, at full load.
Total consumption (approximately equal from part to full load:
2.9 - 3.6 Gal./hour).

Cooling System. (See fig. 2, 3, 7 and 10).

2 Axial Blowers, one on each side driven through shafts and bevel gears from the crankshaft. 4100 RPM at 2000 RPM engine speed. The blowers are working in suction and therefore take in hot air. Oil coolers (two per side) are in parallel with the cylinder blocks. The heat exchange in the oil coolers is 80,000 Calories, (318,000 B.T.U.)per hour. Airflow through one blower: 212 cb.ft./sec., from that 177 cb.ft./sec. to pass over the cylinders and approximately 17.7 cb.ft./sec. through each oil cooler.

Supercharger. (fig. 21).

Two exhaust gas turbo chargers type Buechi, made by Brown Boveri Co., Mannheim. Maximum Speed: 28,000 RPM. Turbine in housing of cast steel, single stage rotor, 4 times sub-divided jet ring, two cylinders exhausting into one pipe which is connected to a quadrant of jets. Maximum exhaust pressure 20.7 p.s.i. (abs.). Maximum tolerated exhaust temperature 1200 degrees F. Blower rotor of steel, enclosed, Maximum Boost Pressure: .93 p.s.i. Delivery: 18 cb.ft./sec.

Air Cleaner.

Turbulence type with 144 cells, of which a part is shut automatically with decreasing air velocity.

Injection System.

Bosch, standard type but modified for drooping "volume per stroke" vs. speed characteristic. Four pumps for four nozzles each. It was planned to change to two pumps with eight outlets each.

Injectors.

Bosch, Mod. S4L, Pintel type. 20 degrees Spray angle. 180 at. Injection Pressure.

Maximum Combustion Pressure.

85 at. - 1200 p.s.i.

Overall Dimensions.

Heights: 90 mm - 36.4". Length: 1150 mm - 45.3". Width, over cyl. heads: appr. 1350 mm - 53". Width, total: 2700 mm - 106".

V. DISCUSSION OF SPECIAL FEATURES

Characteristic. The principal problem in connection with this engine, supercharged by exhaust turbo blower, evidently, resided in obtaining a torque characteristic suitable for its vehicular application, namely a torque curve which peaks at the low end of the usable speed range and has only a slight decline up to the power peak. (See fig. 22).

Obviously if a normally designed engine is equipped with an exhaust driven supercharger a torque characteristic will result which peaks at the high end of the speed range.

In order to obtain, under these conditions, the proper torque vs. speed characteristic, modifications become necessary which affect the fuel pump, the turbo blower and the valve timing.

The standard Bosch fuel pumps have been modified for the SLa 16 engine to produce a drooping characteristic of the volume per stroke vs. speed, which, in turn, causes a diminishing of the normal exhaust pressure with increasing speed. (See fig. 23).

To reduce the normal delivery of the turbo blower with increasing speed, the blades were made smaller and modified in shape. An additional reduction was apparently obtained by omission of an intercooler behind the blower due to which the combustion air enters the cylinder at top engine speed with a temperature of approximately 180 to 200 degrees F. This reduction is illustrated by the fact that the air charge ratio with respect to displacement on the intake side, ahead of the valve is 1.2 at 1600 RPM and only 1.05 at 2000 RPM.

To obtain the required torque value at low speed it became obviously, necessary to over dimension the blowers and modify the valve timing, the latter, not only to provide the proper exhaust pressure but, by an overlap of 135 degrees, (crankshaft) improved low speed scavenging.

The effect of these modifications is expressed in the torque vs. speed curve (given therein as a B.M.E.P. curve) of the Performance Diagram, figure 16; which represents a practically desirable torque condition.

Combustion Chamber. (fig. 18 and 25). To adapt the engine to supercharged operation, much thought seems to have been given to the development of the combustion and especially the pre-combustion chamber.

Attention is called to the fact that the upper part of the pre-chamber is a properly shaped cavity in a separate Aluminum

casting, while only the lower part and the discharge jet is made of heat resisting steel. (19% Chromium). Apparently the former has been done to protect, by good heat exchange to the well ribbed casting, the injector nozzle from overheating and coking.

The opening of the pre-chamber to the combustion chamber proper is in the shape of an oval slot (Maul Brenner) by which means, and also by the form of the piston head a proper spreading and turbulence of the injection as well as scavenging of the pre-chamber is obtained. Further cooling of the combustion chamber was effected by the previously mentioned large valve overlap.

<u>Balance</u>. It is pointed out that the flat "X" arrangement of the pistons with four cranks is favorable in respect of balance, and that with the addition of two idler shafts a complete balance could be obtained. However, the relative crank angles are of great importance and it is only the arrangement adopted in the SLa 16 engine (See fig. 9) which produces a minimum of unbalance.

<u>Cooling</u>. The cooling system has been designed as a suction system, mainly for the reason that thereby negative pressure is produced in the engine compartment and gases are prevented to escape into other parts of the tank. It offers, however, the additional advantage that it is relatively easy to control the parallel airstreams through the cylinder blocks and oil coolers respectively.

Since the two blowers take in air that has already passed the cylinders or the oil coolers, it is obvious that with full load they will deliver less weight of air than at part load, and therefore must be of higher capacity, than in a pressure system.

The blowers are designed with one set of stationary blades on the exhaust side only. It was planned, however, to provide for the production, an additional set of stationary blades on the intake side.

The hottest point of the engine, the head in the region between the valves, is held to a maximum temperature of 280 degrees C. (536 degrees F.)

The pressure drop from one side of the cylinder to the other is 160 mm of water.

The power requirement for both blowers at 2000 RPM crankshaft speed is approximately 80 HP.

The ratio of cooling air to combustion air is 10:1.

In respect to the cooling a few comparative figures may be of interest. The requirement of cooling air per cylinder of the SLa 16 engine is 34 kg/hour. This figure is in the order of 24 kg/hour for aircraft engines and is 54 kg/hour for a 5 liter, 4 cylinder, aircooled Deutz Diesel engine.

Valve Mechanism. (See fig. 24). Although there is nothing radically new in the valve mechanism of the SLa 16 engine, it deserves attention as another one of the many solutions on German engines to control inclined valves from one camshaft.

Cylinder Head. (See fig. 26). The design of the cylinder head is well worth studying for the expert handling of the port and rib arrangement, to effect best heat exchange. Also in this respect, the connection to the cylinder and the omission of the head gasket should be noted.

Muffler. No muffler was found necessary behind the exhaust turbine supercharger.

TABLE OF ENGINES FOR HEAVY ARMOURED VEHICLES IN DEVELOPMENT WITHIN THE LAST YEARS OF THE WAR

(Supplied by Dipl. Ing. E. Haustein from memory)

Manufacturer	Power	Type	Cooling	Cycle	Displacement	Supercharged	Remarks
Simmering Graz Pauker A.G.	720/800	D	Air	4	16 x 135/160 36.8 l	Exhaust Turb.	Ready for production - o.k.
MAN - Argus	700	D	Air	4	16 x 130/165 35 l	Exhaust Turb.	Not fully developed.
Austro-Saurer	700	D	Air	2	?	?	Failure
Deutz	700/800	D	Air	2	V 8 32.6 l	Blower Scavenging	In experimental stage.
Daimler-Benz	1000 1200	O	Air	4	44 l	?	?
BMW	550	O	Air	4	9 cyl. rad. Displ. ?	?	o.k.
Auto - Union	300/350	O	Liquid	4	12 x 140/145	no	o.k.

Fig. 1 - Table of Engines

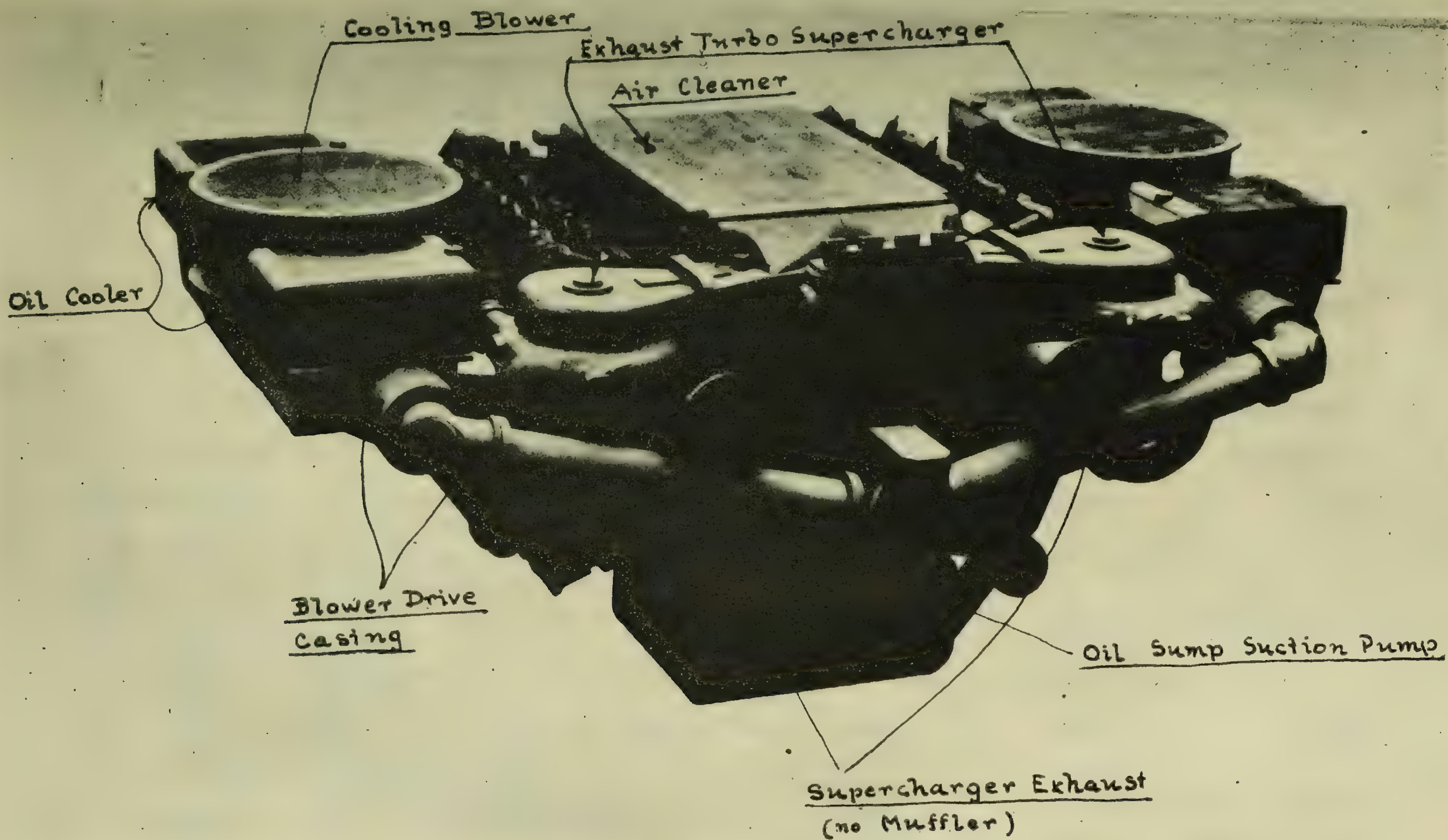
Cooling Blower
Exhaust Turbo Supercharger
Air Cleaner
Oil Cooler
Blower Drive
Casing
Oil Sump Suction Pump
Supercharger Exhaust
(no Muffler)

Fig. 2 Mock Up

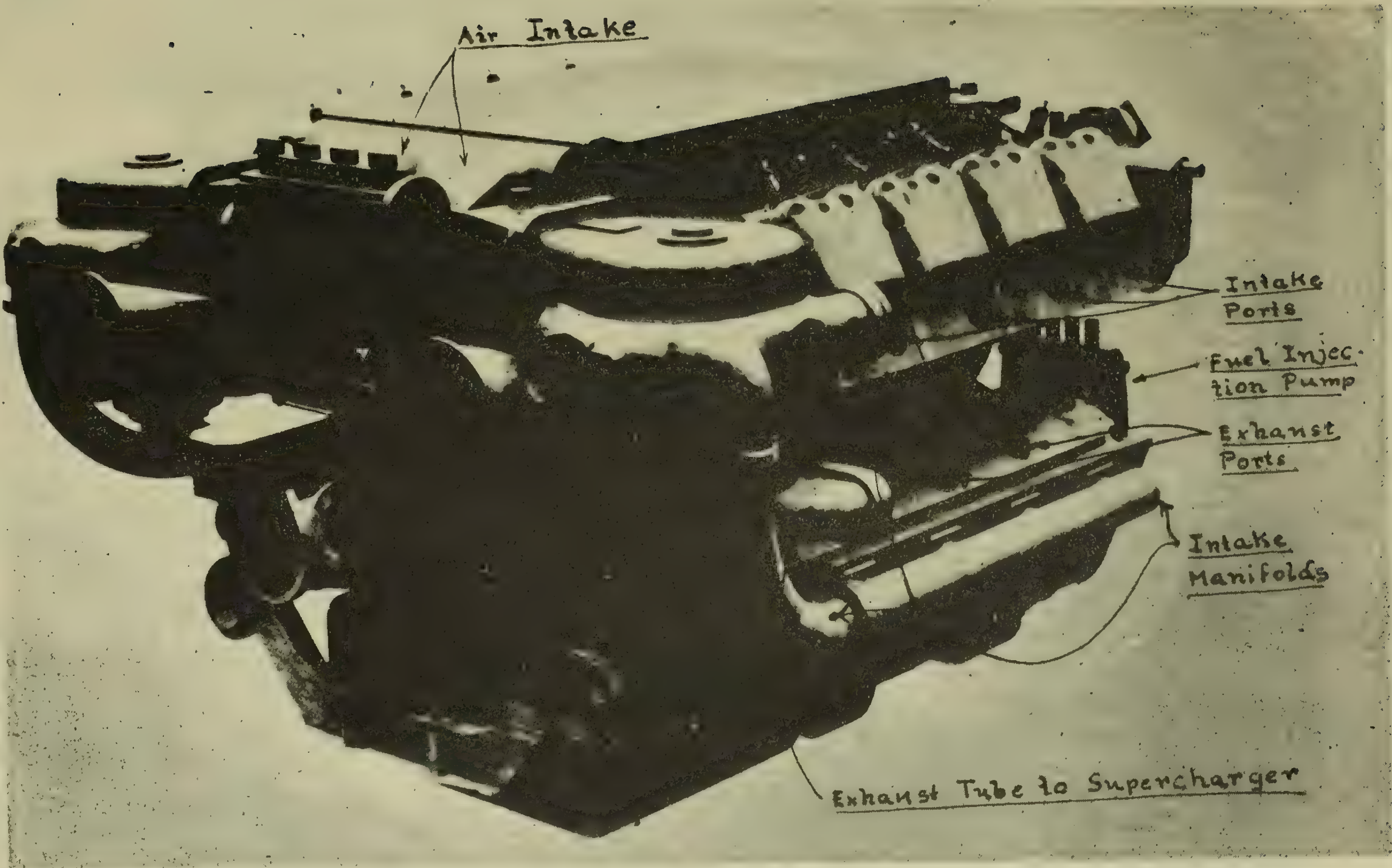
Air Intake
Intake Ports
Fuel Injection Pump
Exhaust Ports
Intake Manifolds
Exhaust Tube to Supercharger

Fig. 3 Mock Up

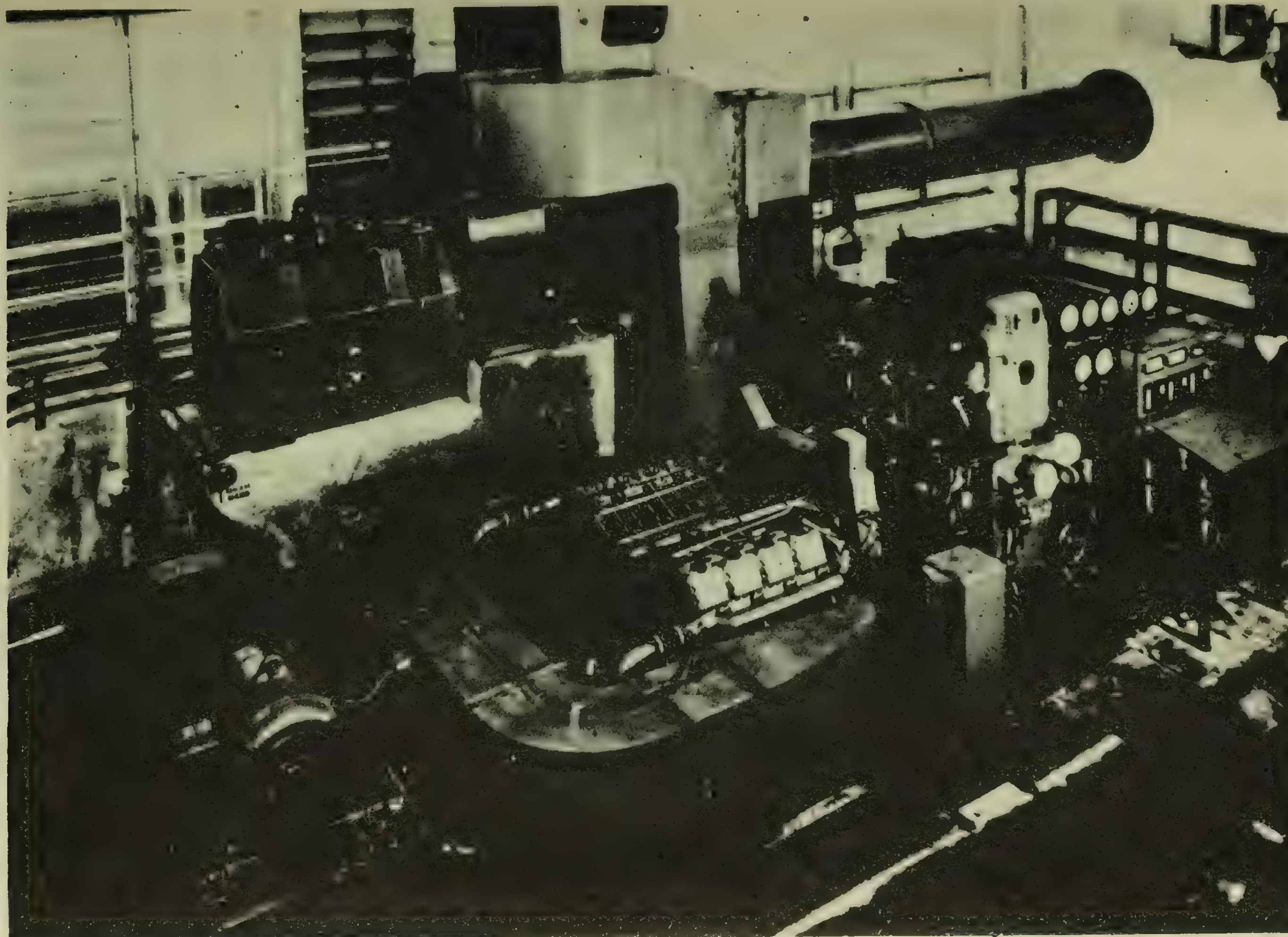

Fig. 4 Engine on Test-Block

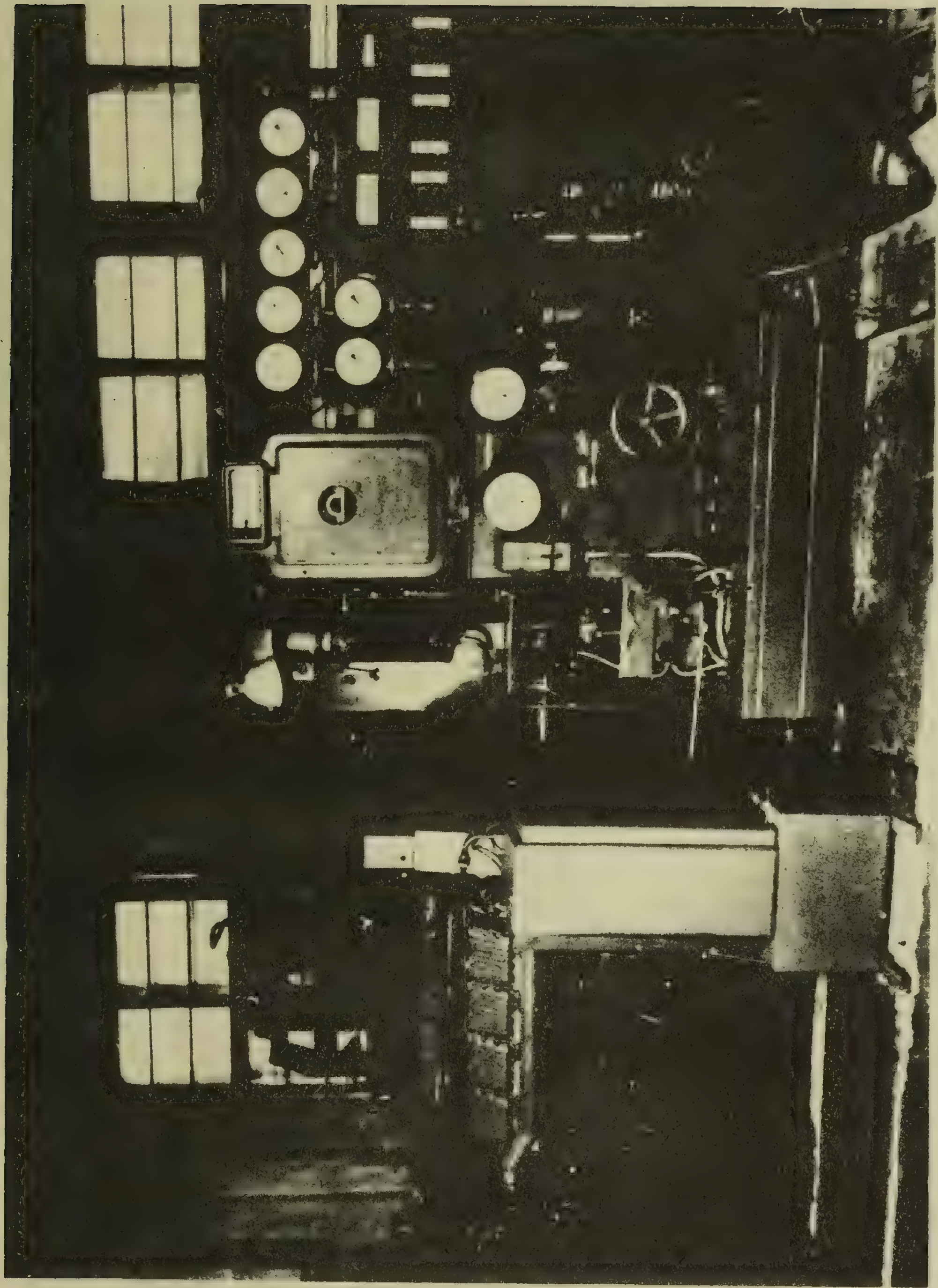

Fig. 5 Engine on Test-Block

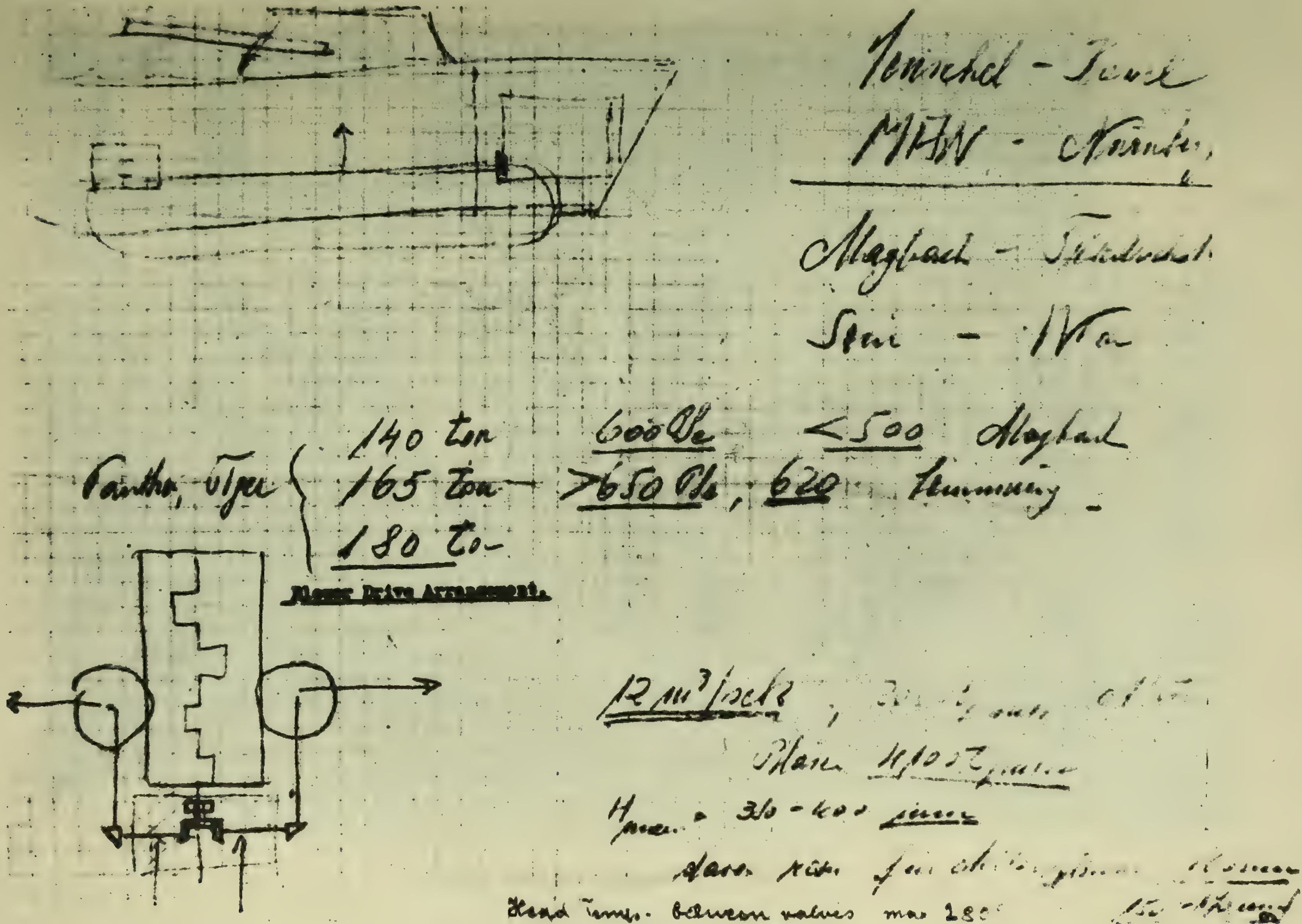

Fig. 6 Blower Drive Arrangement

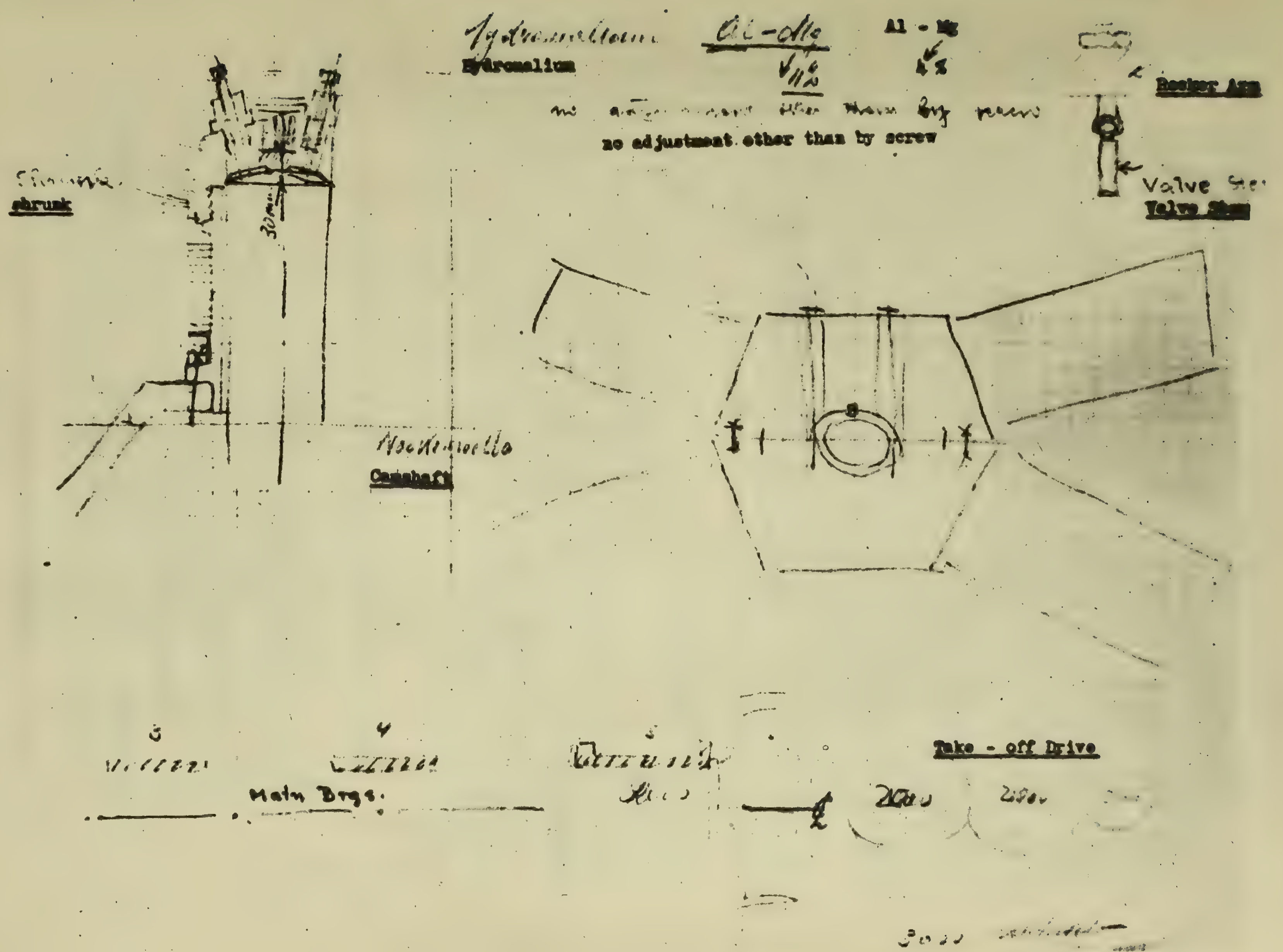

Fig. 7 Sketches

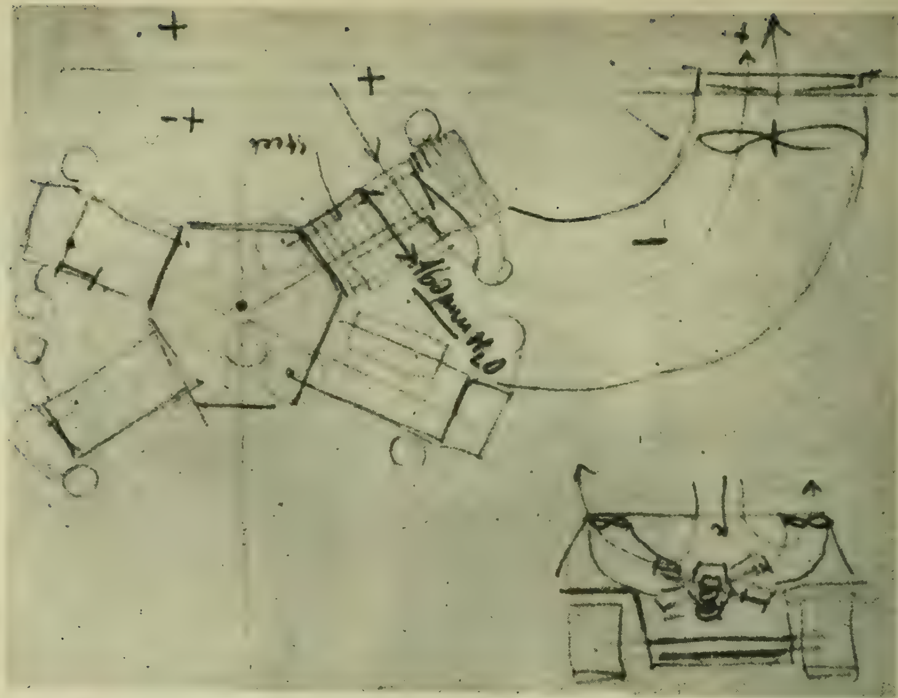

Fig. 8 General Arrangement of the SLa 16 Engine and Installation

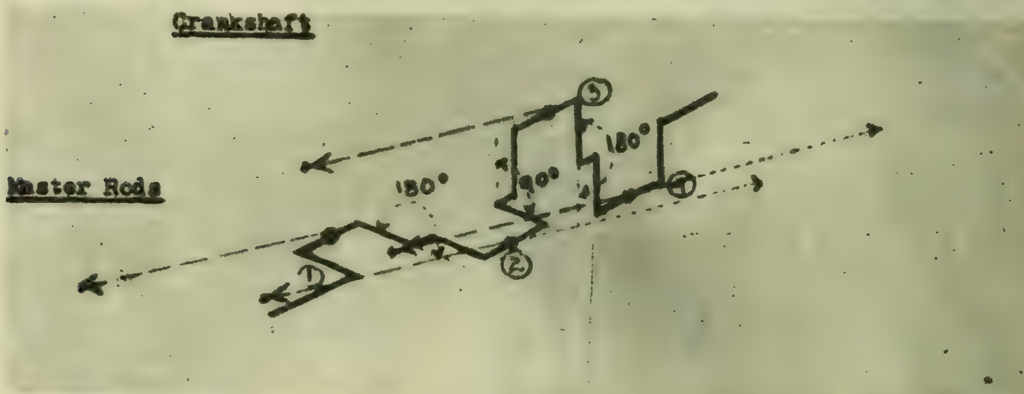

Fig. 9 Projected Position of Master Rods #2 and #4

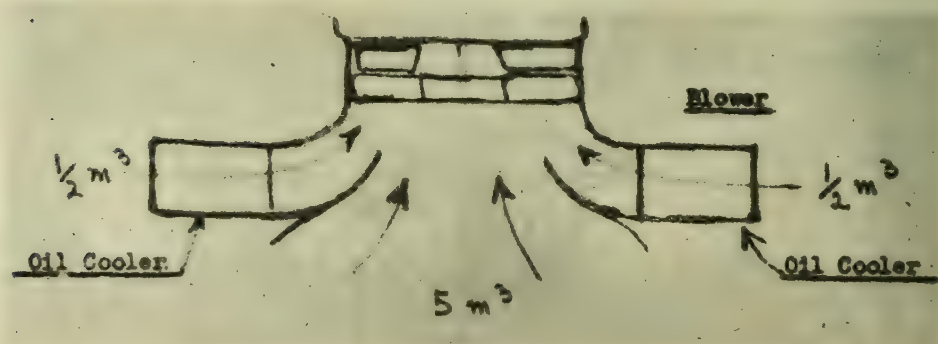

Fig. 10 Schematic Arrangement of the Air Cooling

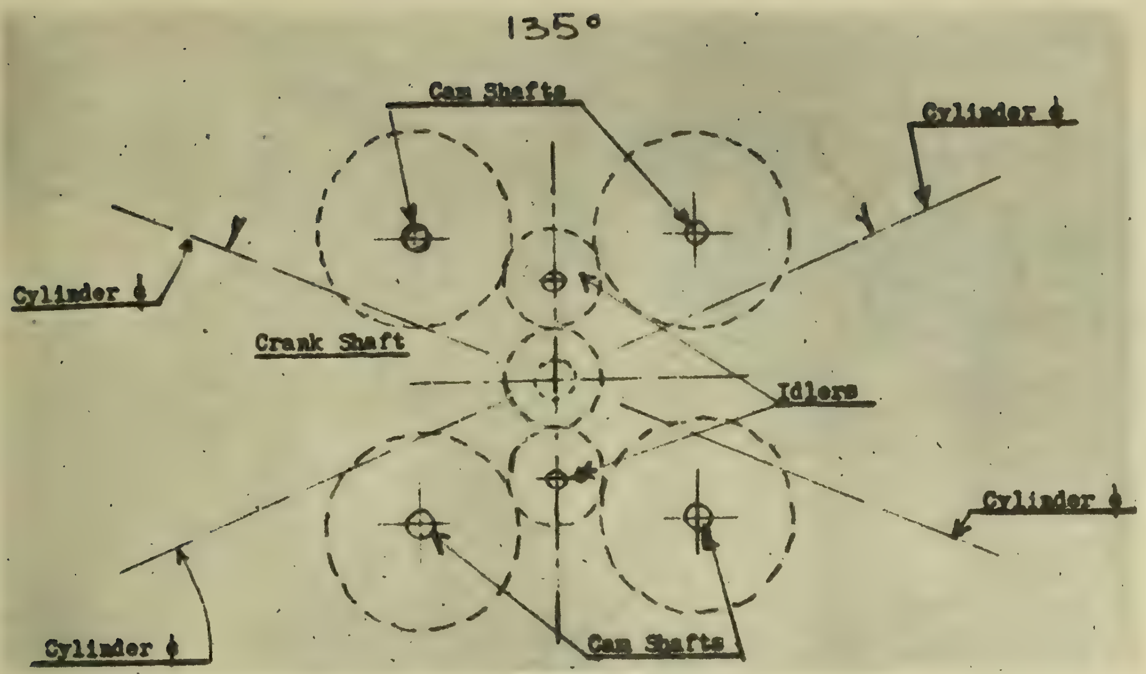

Fig. 11 Timing Gear Drive (behind Take-off Gear Drive)

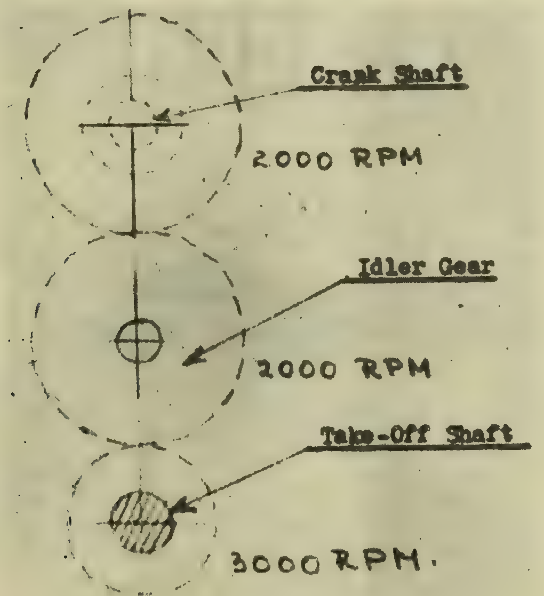

Fig. 12 Take-off Gear Drive

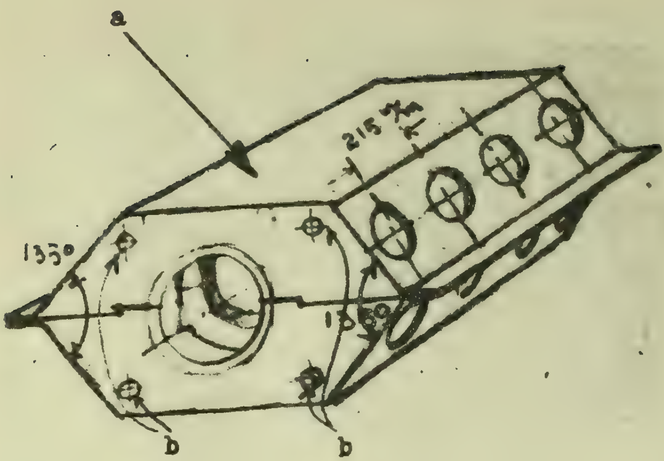

Figure 13 - Crank Case

a. 2-part welded steel
b. Cam-shaft bearing

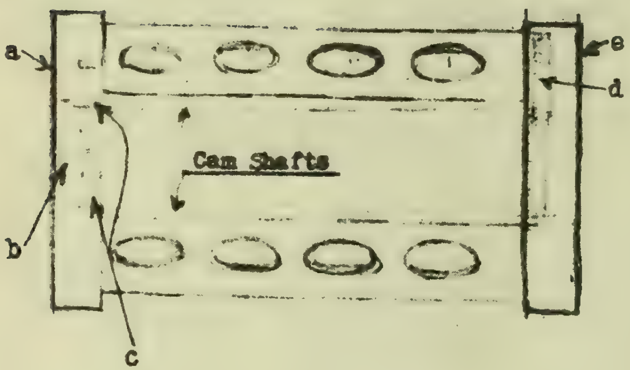

Figure 14 - Crank Case

a. Rear Gear Case
b. Take-off Gear
c. Timing Gears
d. Lubricating Pump Gear
e. Front Gear Case

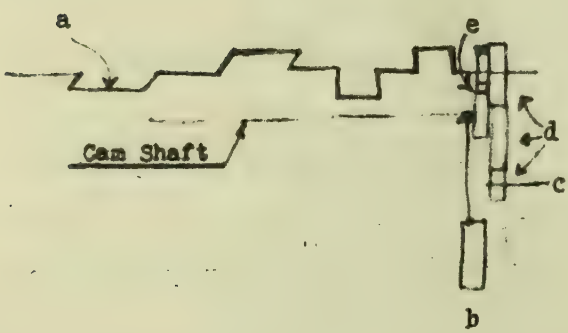

Figure 15 - Take-off and Injection Pump Drive

a. Crank Shaft
b. Fuel Injection Pump
c. Take-off Shaft
d. Take-off Gears
e. Timing Gears

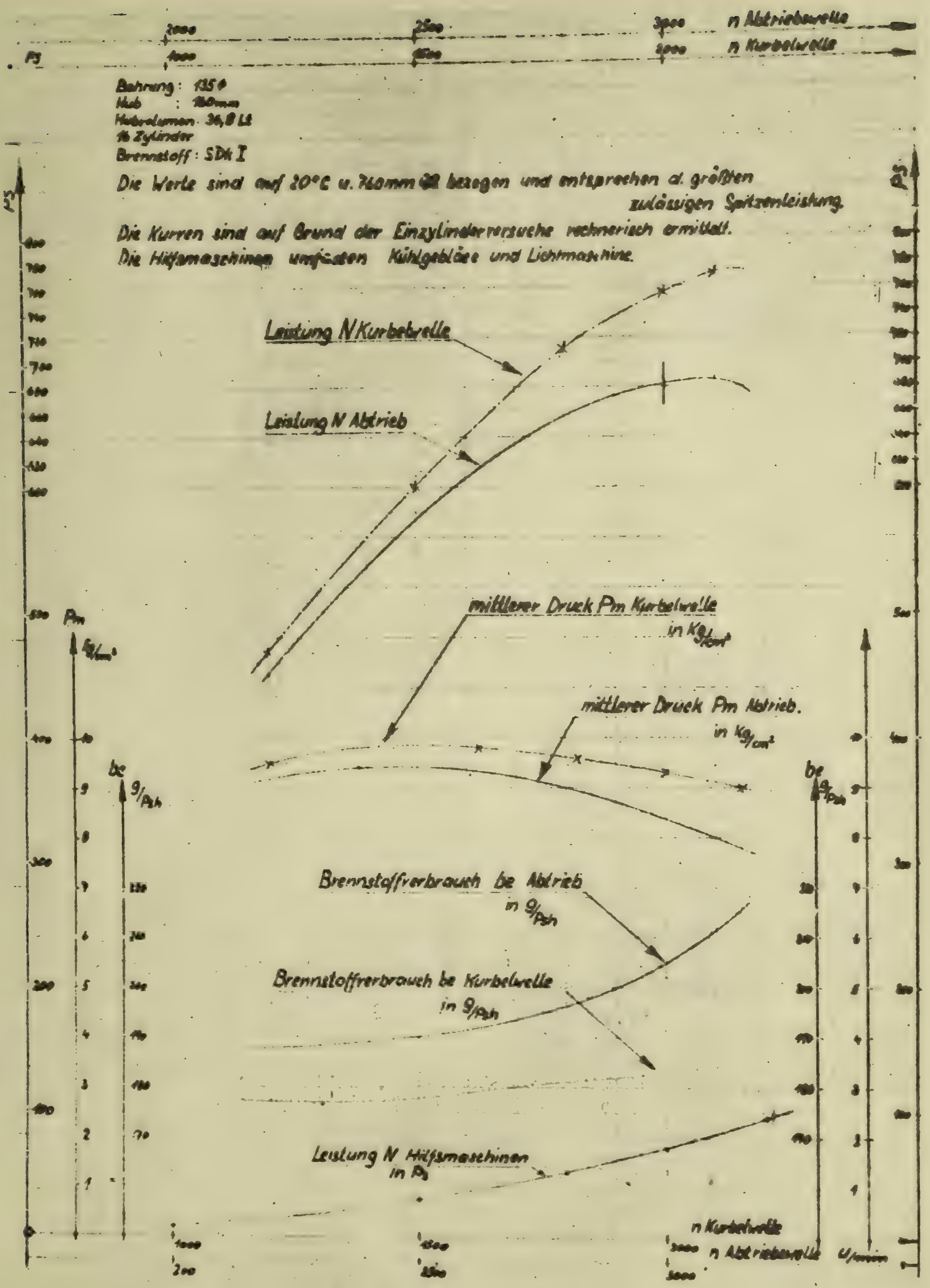

Fig. 1b Performance

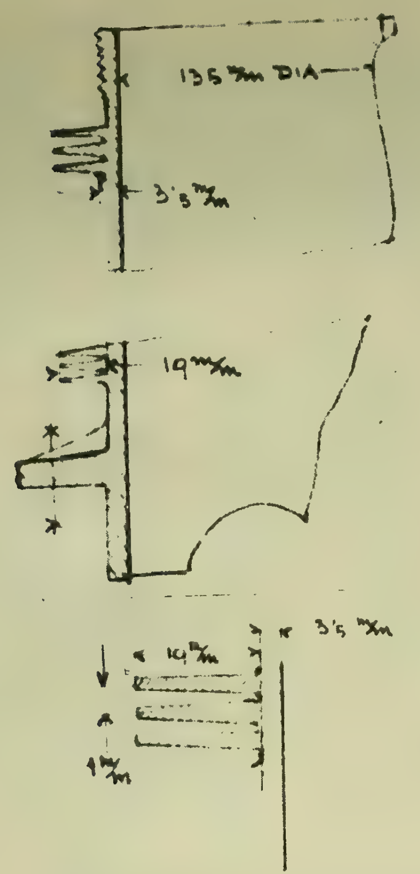

Fig. 17 Cylinder

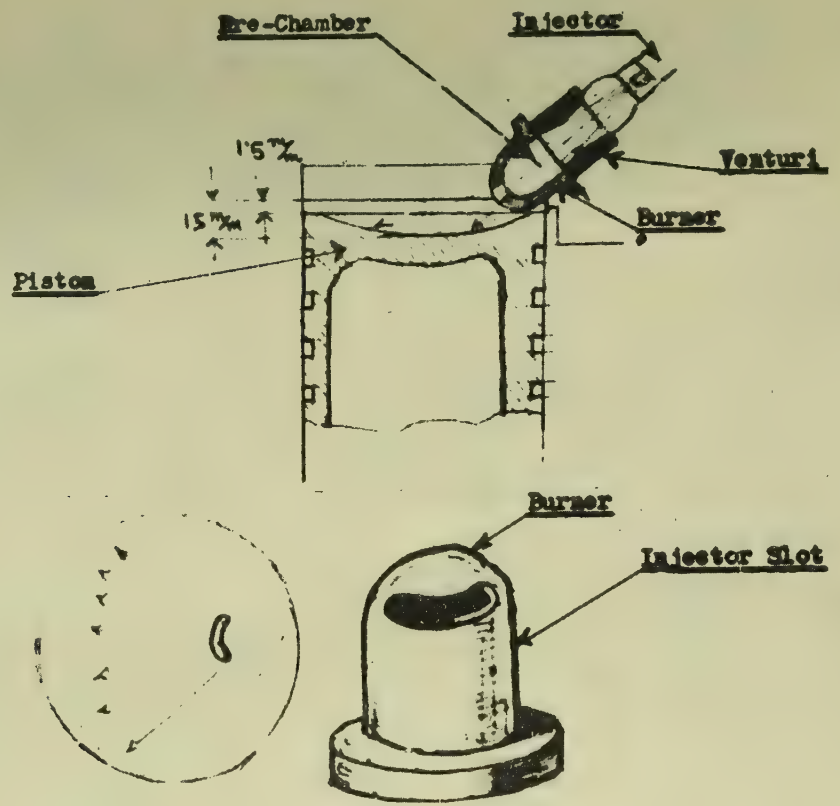

Fig. 18 Combustion Pre-Chamber and Piston

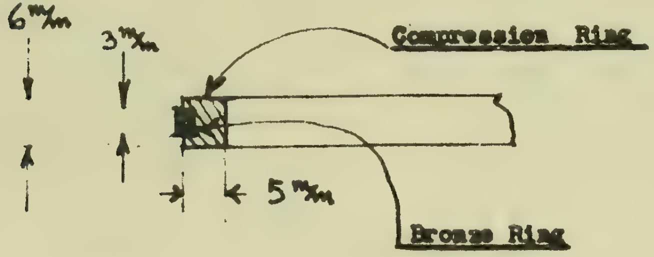

Fig. 19 Piston (Compression) Ring

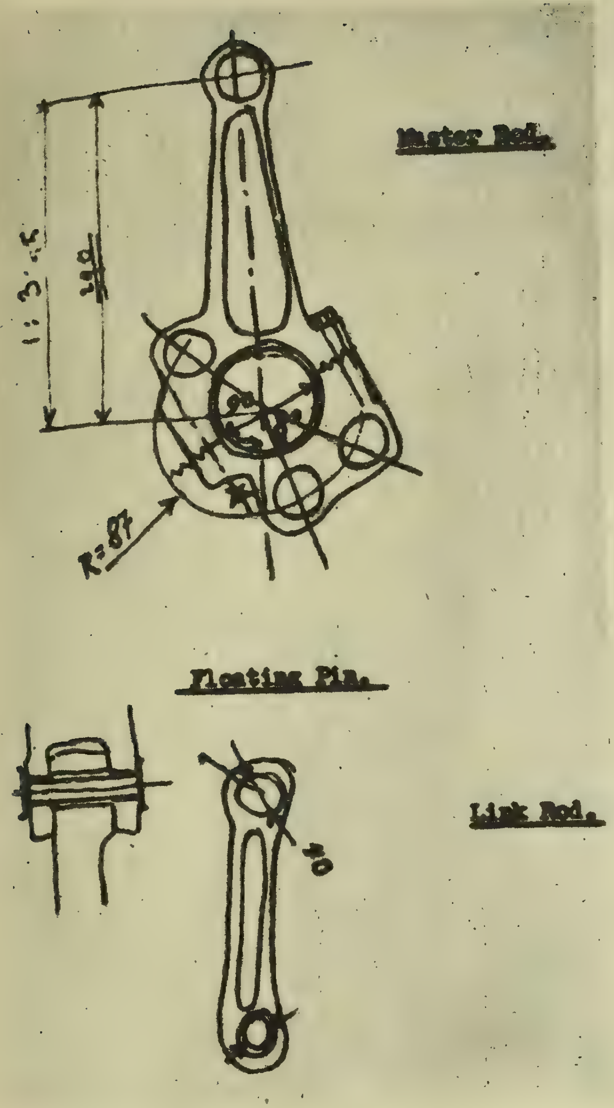

Fig. 20 Master & Link Rods

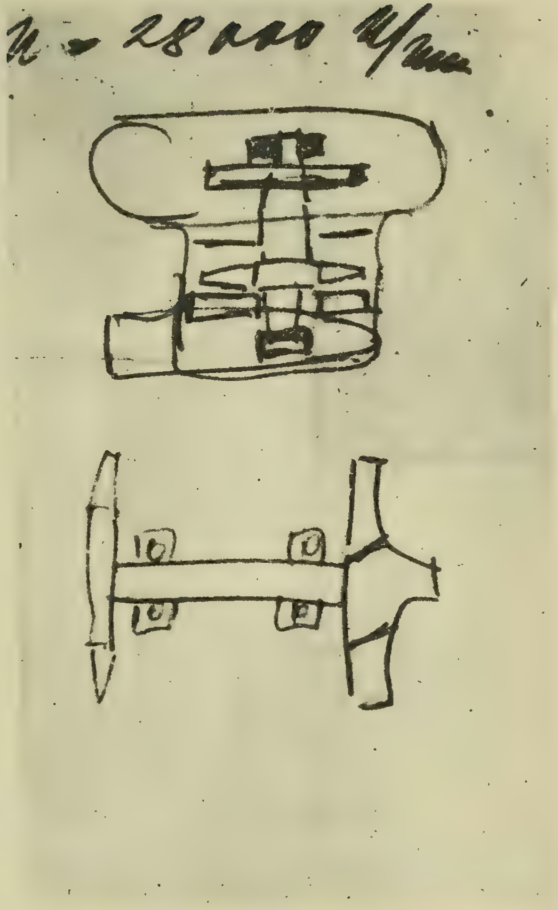

Fig. 21 Buechi Exhaust Turbine Supercharger

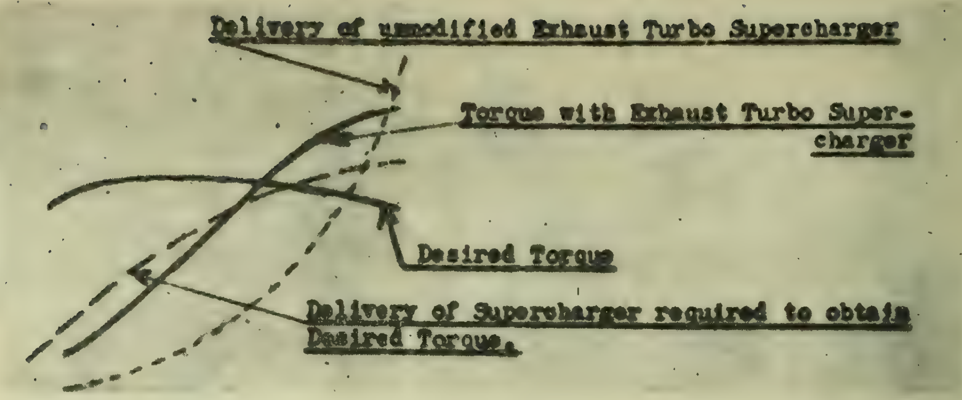

Fig. 22 Diagram

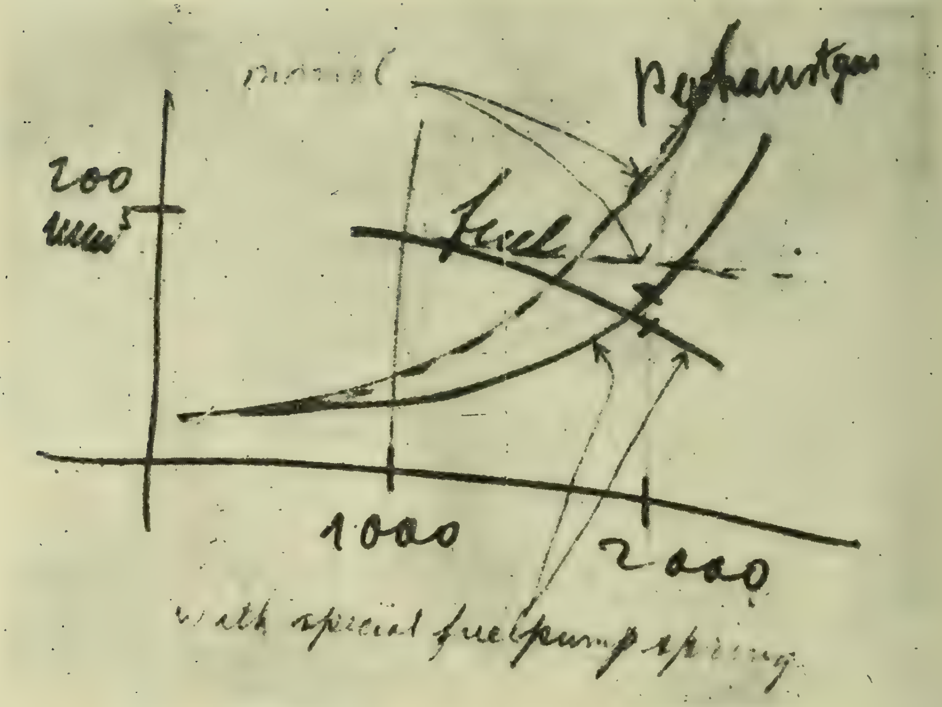

Fig. 23 Diagram

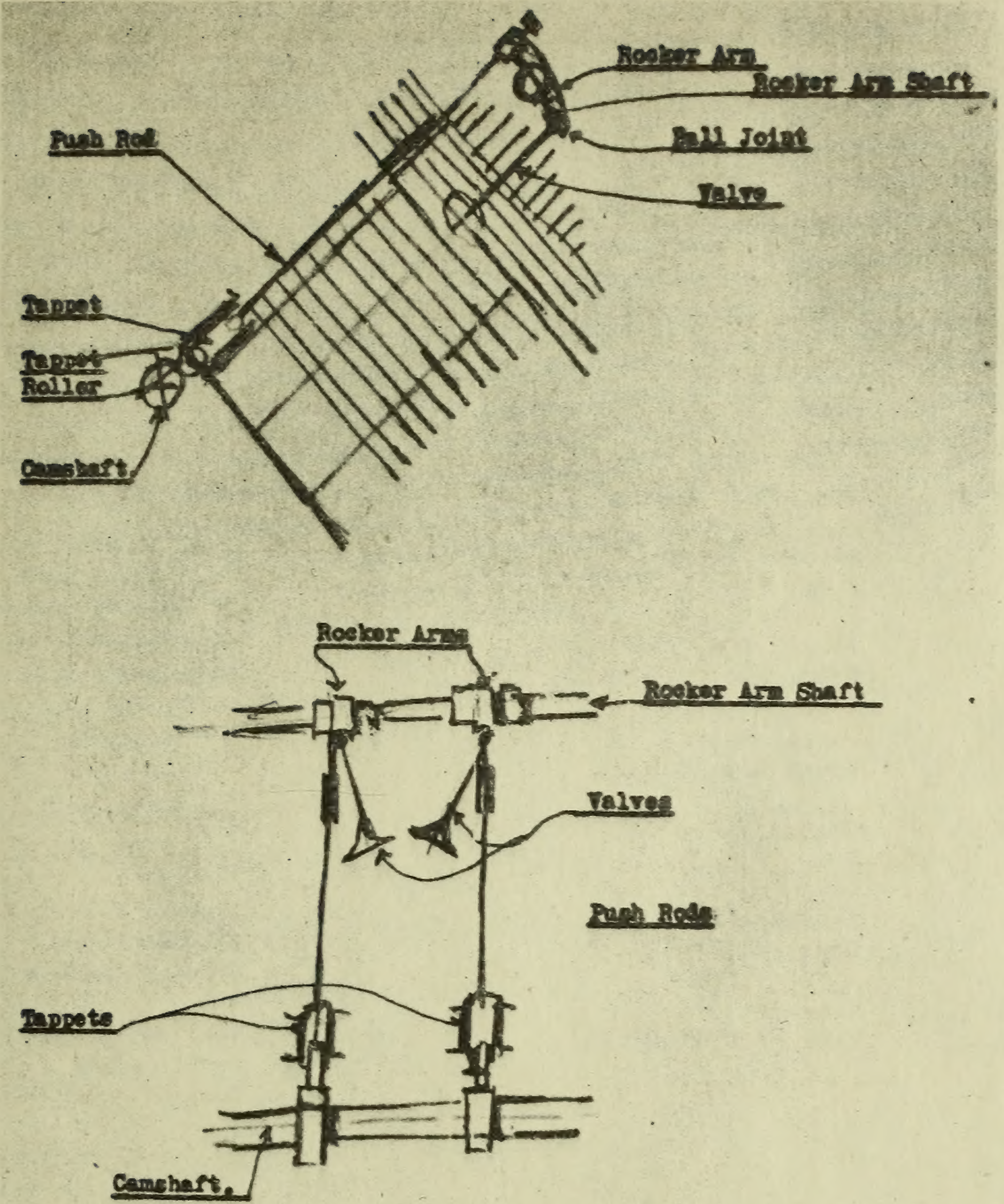

Fig. 24 Valve Timing

The following prints were so nearly destroyed that any local handling to include reproductions in this report was too hazardous. They were forwarded to the Joint Intelligence Objectives Agency, Room 2213 Munitions Building, Washington, D. C.

Fig.	
25	Cylinder and Head Assembly Drwg. #1B.16.04.00
26	Cylinder Head Drwg. #1A.16.04.01
27	Inlet Valve Drwg. #1E.16.05.01
28	Exhaust Valve Drwg. #1E.16.05.02
29	Rocker Arm Drwg. #16.05.07
30	Tappet Body Drwg. #16.05.23
31	Tappet Roller Drwg. #16.05.25
32	Crankshaft Drwg. #1B.16.02.38
33	Camshaft Drwg. #1C.16.05.28

Fig.	
34	Master Rod Drwg. #16.03.12/13.1
35	Link Rod Drwg. #16.03.03.2
36	Link Rod Connection Assembl Drwg. #16.03.04
37	Link Rod Pin Drwg. #16.03.05
38	Link Rod Pin Endplate Drwg. #16.03.09
39	Bearing - Master Rod Drwg. #16.03.12/13.1
40	Bearing - Wrist Pin Drwg. #16.03.08
41	Bearing - Link Rod Pin - of Master Rod Drwg. #16.03.06
42	Bearing - Link Rod Pin - of Link Rod Drwg. #16.03.07